533 Rec'd PCT/PTO 07 SEP 2001

FORM PTO-1390 (REV 11-2000)	U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE	ATTORNEY'S DOCKET NUMBER 36-1472
TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371		U.S. APPLICATION NO. (If known, see 37 C.F.R. 1.5) 09/936049 Unknown
INTERNATIONAL APPLICATION NO. **PCT/GB00/01155**	INTERNATIONAL FILING DATE **27 March 2000**	PRIORITY DATE CLAIMED **31 March 1999**

TITLE OF INVENTION

COMMUNICATIONS NETWORK

APPLICANT(S) FOR DO/EO/US

POUSTIE

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☒ This is an express request to begin national examination procedures (35 U.S.C. 371(f)). The submission must include items (5), (6), (9) and (21) indicated below.
4. ☒ The U.S. has been elected by the expiration of 19 months from the priority date (Article 31).
5. ☐ A copy of the International Application as filed (35 U.S.C. 371(c)(2)).
   a. ☒ is attached hereto (required only if not communicated by the International Bureau).
   b. ☒ has been communicated by the International Bureau.
   c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US).
6. ☐ An English language translation of the International Application as filed (35 U.S.C. 371(c)(2)).
   a. ☐ is attached hereto.
   b. ☐ has been previously submitted under 35 U.S.C. 154(d)(4).
7. ☐ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371(c)(3))
   a. ☐ are attached hereto (required only if not communicated by the International Bureau).
   b. ☐ have been communicated by the International Bureau.
   c. ☐ have not been made; however, the time limit for making such amendments has **NOT** expired.
   d. ☐ have not been made and will not be made.
8. ☐ An English language translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
9. ☒ An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)).
10. ☐ A English language translation of the annexes of the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

Items 11 To 20 below concern document(s) or information included:

11. ☐ An Information Disclosure Statement under 37 C.F.R. 1.97 and 1.98.
12. ☒ An assignment document for recording. A separate cover sheet in compliance with 37 C.F.R. 3.28 and 3.31 is included.
13. ☒ A FIRST preliminary amendment.
14. ☐ A SECOND or SUBSEQUENT preliminary amendment.
15. ☐ A substitute specification.
16. ☐ A change of power of attorney and/or address letter.
17. ☐ A computer-readable form of the sequence listing in accordance with PCT Rule 13ter.2 and 35 U.S.C. 1.821-1.825.
18. ☐ A second copy of the published international application under 35 U.S.C. 154(d)(4).
19. ☐ A second copy of the English language translation of the international application under 35 U.S.C. 154(d)(4).
20. ☒ Other items or information. Amended Sheets: pages 26 and 27 with claims 1 through 8

JC12 Rec'd PCT/PTO 07 SEP 2001

U.S. APPLICATION NO. (If known, see 37 C.F.R. 1.5) Unknown 09/936049	INTERNATIONAL APPLICATION NO. PCT/GB00/01155	ATTORNEY'S DOCKET NUMBER 36-1472

21. ☒ The following fees are submitted:		CALCULATIONS	PTO USE ONLY
BASIC NATIONAL FEE (37 C.F.R. 1.492(a)(1)-(5):			
-- Neither international preliminary examination fee (37 C.F.R. 1.482) nor international search fee (37 C.F.R. 1.445(a)(2)) paid to USPTO and International Search Report not prepared by the EPO or JPO $1000.00			
-- International preliminary examination fee (37 C.F.R. 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO....................$860.00			
-- International preliminary examination fee (37 C.F.R. 1.482) not paid to USPTO but international search fee (37 C.F.R. 1.445(a)(2)) paid to USPTO........................$710.00			
-- International preliminary examination fee (37 C.F.R. 1.482) paid to USPTO but all claims did not satisfy provisions of PCT Article 33(1)-(4)..............................$690.00			
-- International preliminary examination fee (37 C.F.R. 1.482) paid to USPTO and all claims satisfied provisions of PCT Article 33(1)-(4)......................................$100.00			
ENTER APPROPRIATE BASIC FEE AMOUNT =	$	860.00	
Surcharge of $130.00 for furnishing the oath or declaration later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 C.F.R. 1.492(e)).	$	0.00	

CLAIMS	NUMBER FILED		NUMBER EXTRA	RATE				
Total Claims	8	-20 =	0	X	$18.00	$	0.00	
Independent Claims	3	-3 =	0	X	$80.00		0.00	
MULTIPLE DEPENDENT CLAIMS(S) (if applicable)				$270.00		$	0.00	
					TOTAL OF ABOVE CALCULATIONS =	$	**860.00**	

☐ Applicant claims small entity status. See 37 CFR 1.27. The fees indicated above are reduced by 1/2.		0.00	
SUBTOTAL =	$	**860.00**	
Processing fee of $130.00, for furnishing the English Translation later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 C.F.R. 1.492(f)). +		0.00	
TOTAL NATIONAL FEE =	$	**860.00**	
Fee for recording the enclosed assignment (37 C.F.R. 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 C.F.R. 3.28, 3.31). **$40.00** per property +	$	40.00	
Fee for Petition to Revive Unintentionally Abandoned Application ($1240.00 – Small Entity = $620.00)	$	0.00	
TOTAL FEES ENCLOSED =	$	**900.00**	
	Amount to be: refunded	$	
	Charged	$	

a. ☒ A check in the amount of $900.00 to cover the above fees is enclosed.

b. ☐ Please charge my Deposit Account No. 14-1140 in the amount of $_____ to cover the above fees. A duplicate copy of this form is enclosed.

c. ☒ The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. 14-1140. A duplicate copy of this form is enclosed.

d. ☒ The entire content of the foreign application(s), referred to in this application is/are hereby incorporated by reference in this application.

NOTE: Where an appropriate time limit under 37 C.F.R. 1.494 or 1.495 has not been met, a petition to revive (37 C.F.R. 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO:

NIXON & VANDERHYE P.C.
1100 North Glebe Road, 8th Floor
Arlington, Virginia 22201-4714
Telephone: (703) 816-4000

Larry S. Nixon
SIGNATURE

Larry S. Nixon
NAME

25,640 **September 7, 2001**
REGISTRATION NUMBER Date

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Patent Application of

POUSTIE Atty. Ref.: **36-1472**

Serial No. **Unknown** Group:

National Phase of: **PCT/GB00/01155**
International Filing Date: **27 March 2000**

Filed: **September 7, 2001** Examiner:

For: **COMMUNICATIONS NETWORK**

* * * * * * * * * * *

September 7, 2001

Assistant Commissioner for Patents
Washington, DC 20231

Sir:

PRELIMINARY AMENDMENT

Prior to calculation of the filing fee and in order to place the above identified application in better condition for examination, please amend the claims as follows:

IN THE CLAIMS

Please substitute the following amended claims for corresponding claims previously presented. A copy of the amended claims showing current revisions is attached.

4. (Amended) A method as claimed in claim 2, wherein said chirped pulses have a duration T, and said wavelength of said chirped pulses varies in a predetermined monotonic manner over said duration T of said chirped pulses.

5. (Amended) A method as claimed in claim 2, wherein if the duration of the chirped pulses is T, the data rate of the chirped pulses is 1/T.

REMARKS

Attached hereto is a marked-up version of the changes made to the claims by the current amendment. The attached page is captioned "**Version with markings to show changes made**."

The above amendments are made to place the claims in a more traditional format.

Respectfully submitted,

NIXON & VANDERHYE P.C.

By: Larry S. Nixon

Larry S. Nixon
Reg. No. **25,640**

LSN:lmy

1100 North Glebe Road, 8th Floor
Arlington, VA 22201-4714
Telephone: (703) 816-4000
Facsimile: (703) 816-4100

VERSION WITH MARKINGS TO SHOW CHANGES MADE

4. (Amended) A method as claimed in claim 2 [or claim 3], wherein said chirped pulses have a duration T, and said wavelength of said chirped pulses varies in a predetermined monotonic manner over said duration T of said chirped pulses.

5. (Amended) A method as claimed in claim 2 [or claim 3], wherein if the duration of the chirped pulses is T, the data rate of the chirped pulses is 1/T.

09/936049

JC12 Rec'd PCT/PTO 07 SEP 2001

10/prts

COMMUNICATIONS NETWORK

The present invention relates to a communications network and to a method and device for retiming a data pulse carried on such a network, in particular for correcting for timing fluctuations.

It is known that optical fibre has a huge potential information-carrying capacity. For example, by utilising the entire gain bandwidth of erbium-doped optical amplifiers, a single fibre could carry more than 2 Tbit/s. However in the majority of telecommunications systems in commercial use currently, the information is carried over fibre in the form of an optical signal at a single wavelength. The data transmission bandwidth of the fibre is therefore limited by the electrical bandwidth of the transmitter and receiver, and this means that only a tiny fraction (a maximum of about 1%) of the potential bandwidth-carrying capacity of the fibre is being usefully exploited. There is therefore much interest currently in developing methods for increasing the transmission rate for point-to-point fibre links. One method is wavelength-division multiplexing (WDM), in which several data channels, at different wavelengths, are carried simultaneously on the same fibre. An alternative method for increasing the rate of information that can be carried on fibre is to use optical time-division multiplexing (OTDM) in which several data channels are multiplexed in the form of bit-interleaved return-to-zero (RZ) optical pulse trains.

The WDM approach to photonic networking has some very attractive advantages: in addition to the relative simplicity and commercial availability of the devices needed, WDM networks can be created in a wide variety of architectures with great flexibility (the main restriction being merely that any pair of photonic transmission paths cannot use the same wavelength on a shared fibre link). An advantage of WDM networks is that they can, in principle, support 'signal transparency', i.e. data signals can be carried using any modulation format. However, this implies that, in effect, WDM photonic networks are based on 'analogue' transmission. As a result it is not possible for digital signal regeneration techniques in the optical domain, to be used. The inability to perform signal regeneration in the optical domain leads to practical scaling limitations for WDM networks due to noise accumulation from optical amplifiers, crosstalk and nonlinearity. These factors restrict the number of network switching

nodes through which signals can pass without fatal degradation. Currently, in reported laboratory experiments the maximum number of WDM switching nodes through which a signal can pass without regeneration is limited to around 10, which is a significant restriction in architecture and scalability. A feasible, though costly, solution currently being advocated by some equipment vendors is to sacrifice transparency, standardise the transmission format, and regenerate each wavelength channel individually at the outputs of WDM cross-connects. In effect, this is a hybrid arrangement using analogue switching together with channel-by-channel digital regeneration.

In the OTDM approach to photonic networking, the signals are carried in 'digital' format in the form of RZ optical pulses, allowing the use of digital signal regeneration techniques in the optical domain such as 3R (Re-amplify, Re-time and Re-shape) regeneration [Lucek J K and Smith K,Optics Letters, 18, 1226-28 (1993)] or soliton-control techniques [Ellis A D, Widdowson T, Electronics Letters, 31, 1171-72 (1995)]. These techniques can maintain the integrity of the signals as they pass through a very large number of nodes. For example, Ellis and Widdowson [Ellis A D, Widdowson T, Electronics Letters, 31, 1171-72 (1995)] have made a laboratory demonstration of error-free transmission of signals through an OTDM network consisting of 690 nodes in concatenation. Despite this impressive potential for scalability, however, the OTDM approach to photonic networking suffers from severe restrictions in the network architecture that can be used. This results from the need to maintain proper bit-level synchronism between all the signal sources, demultiplexers and channel add/drop multiplexers throughout the network.

The problems with the conventional techniques discussed above, are that in complex architectures, timing fluctuations of the data pulses in the arrival time of pulses at nodes (due to environmental effects acting on the fibres such as temperature change and mechanical strain) cannot be adequately controlled or compensated in a continuous uninterrupted fashion. This results in data pulses being lost. There are many causes of timing fluctuations that may result in data being lost. The first cause is jitter in the arrival time of the incoming packet data pulses. It is known that in high-speed optical transmission systems, jitter in the arrival time of pulses arises from effects such as amplified spontaneous emission noise, the soliton

self-frequency shift arising from the Raman effect, soliton short-range interactions, and the complex interplay of these various processes. Other timing fluctuations include temperature dependent length changes in the fibre that cause the absolute arrival time of the optical pulses at a node to wander. This creates timing problems for demultiplexing the data at the node and for adding new local data to the optical stream. Techniques to provide synchronism at nodes and overcome this wander timing problem have been described using discrete wavelength conversion and dispersion compensation (K.S. Jepsen et al, Technical University of Denmark, ECOC '97 postdeadline) but this technique requires feedback to achieve synchronism. The limited bandwidth of such feedback control limits this technique to relatively slow timing changes and not pulse-to-pulse jitter.

Conventional techniques to compensate for timing fluctuations, such as jitter, rely upon a gate window being opened by the timing pulse when it reaches the node. The problem with this technique is that the gate window only has a finite duration, and if a data pulse is affected by jitter to the extent that it does not arrive within the gate window, it will be lost.

The present invention provides a method of correcting for timing jitter, and overcomes some of the disadvantages of the prior art techniques discussed above.

In accordance with a first aspect of the present invention, there is provided a method of correcting for timing jitter of an optical data pulse in an optical transmission system, the method comprising:

i) generating a chirped optical pulse containing a spread of wavelengths;

ii) applying the chirped pulse to one input of an optical AND gate in synchronism with the unjittered arrival time of the data pulse:

iii) applying the optical data pulse to a second input of the optical AND gate to trigger the AND gate and to produce at the output of the AND gate an output optical pulse having a wavelength determined by the amount of jitter experienced by the data pulse with respect to the unjittered arrival time; and thereafter

iv) passing the optical output pulse through a suitable optically dispersive medium so that the output pulse is correctly retimed to compensate for the jitter of the optical data pulse.

According to a second aspect, a device for correcting for timing jitter of optical pulses in an optical transmission system, said device comprising an optical AND gate having an output and first and second inputs, the first input of the AND gate being connected to a source of chirped optical pulses, wherein when one of said optical pulses is received at the second input while one of the chirped pulses is present at the first input, the AND gate is triggered to produce an output optical pulse whose wavelength is determined by the amount of jitter in the optical trigger pulse, said device further comprising an optically dispersive medium having a dispersion profile appropriate for the wavelength profile of said chirped pulses, through which said output pulses pass, so that different wavelength output pulses are temporally shifted in accordance with their wavelength, so that after passage through the dispersive medium said output pulses are correctly retimed.

Thus, in accordance with a first and second aspects of the invention, provided the data signal arrives at the node at the same time the generated pulse arrives at the node, the output pulse generated at the node, arrives at a detector at a predetermined time, independent of the timing fluctuation suffered by the data pulse on arrival at the node.

The device of the present invention is compatible with other optical devices such as optical regenerators and bit-serial optical processing devices.

According to a third aspect, there is provided a use of an optical AND gate and an optical dispersive medium to correct for jitter suffered by optical pulses to provide from optical pulses at one input and chirped pulses from another input, output pulses having a wavelength dependent on the amount of jitter suffered by the optical pulses, so that after passage through the dispersive medium the output pulses are correctly timed.

According to a fourth aspect, there is provided a regenerator including a device according to the second aspect, including a second optical AND gate disposed to receive said output pulses and local clock pulses, wherein said AND gate is arranged so that said output pulses operates on said local clock pulses to produce regenerated pulses having a wavelength determined by said local clock pulse and independent of the wavelength of the pulse received at the second AND gate.

Brief description of the drawings

In order that the invention may be more fully understood embodiments thereof will now be described by way of example, and by way of contrast with a prior art device as previously described, reference being made to the accompanying drawings in which:

Figure 1: shows a device for correcting timing fluctuations suffered by a data pulse according to a first embodiment of the present invention;

Figure 2: shows a device for correcting timing fluctuations suffered by a data pulse, including the data pulse, the generated pulse and the output pulse;

Figure 3: shows a depiction of a prior art timing technique;

Figure 4: shows a device for timing data pulses according to a second embodiment of the present invention;

Figure 5: shows a plurality of chirped pulses ;

Figure 6: shows a representation of how the chirped pulses are generated;

Figure 7: shows a regenerator including a device according to the first embodiment of the present invention;

Figure 8: shows a dual gate bit-asynchronous regenerator with which a device according to the first embodiment of the present invention may be incorporated; and

Figure 9: a sequence of timing diagrams that illustrate the operation of the dual-gate regenerator;

Figure 10 shows a device for quantifying the amount of jitter experienced by an optical data pulse in an optical transmission system.

Detailed description

Figure 3 shows a prior art approach to correcting timing fluctuations of a digital data stream consisting of a RZ (return to zero) pulse train encoded by on-off modulation

("mark" represents a bit value 1, "space" represents 0). The incoming data bits from a distant source 20 are used to modulate using a gate 24, a continuous train of RZ pulses produced by a local source 22, thus regenerating the original data to be detected at remote detector 26. The presence of a "mark" in the incoming data stream causes the gate to open for a time of the order of the bit period, allowing a single pulse from the local source 22 to pass through. In this way the regenerated bits are provided by the local source and hence their pulse shape, spectral quality, amplitude and timing stability are determined by the properties of the local source 22. The pulse repetition rate of this local source 22 is the same as the nominal bit rate of the incoming data. The key problem in designing such a regenerator is to ensure that the incoming data stream and the locally-generated pulses are maintained in synchronism.

Figure 1 is a simplified outline diagram showing a system including a device 8 for correcting timing fluctuations suffered by a data pulse. The system includes an optical data source 30. The optical data source 30 includes a source of optical RZ pulses at a repetition frequency of, for example 10GHz, whose output is modulated and multiplexed in a fashion similar to that used for OTDM (e.g. the output from the pulse source is split into parallel paths which are individually encoded with data by on-off modulation at a particular rate and then recombined by bit-interleaving to form a packet of data bits with a composite rate). The source of pulses at the particular rate could consist of an electronic microwave oscillator oscillating at the same rate which drives an electrically-synchronised laser (such as a gain-switched laser or an actively mode locked laser). Alternatively, it could be a continuously free-running optical pulse source, such as a passively-mode locked laser or a mode locked ring laser, whose nominal repetition frequency is set (for example, by tuning the laser cavity length) to the particular rate.

The device 8 for correcting timing fluctuations includes a continuously free running pulse source 32 for generating chirped pulses. The chirped pulses have a duration T, and have a wavelength which may vary in a predetermined monotonic manner over the duration T of the chirped pulse. The source 32 is independent from the data pulse source 30. The chirped pulse source 32 can be either one which is part of the node, or one that is local to one node, but not part of the node, or remote from the node.

Where the source is remote from a node, a single source could be shared between multiple nodes, although a source may be shared between several nodes and still be part of one of the nodes.

Figure 5 shows the frequency characteristics of the chirped pulses and Figure 6 outlines the generation of the chirped pulses. These aspects are discussed below.

The period of the chirped pulses is controllable. Also, the frequency distribution which makes up the chirped pulses is controllable. The period of the chirped pulses is selected for example depending on the data rate of the data pulses input to the device at the node, or the switching rate at which the node in the device is operating. The frequency distribution is selected depending on, for example, what value of dispersion compensation is required. For example, the chirped pulses generated as shown in Figure 5 and 6 have a duration T of 25ps, and have a frequency distribution from 0 to 600 GHz. Depending on the particular situation, the period and frequency distribution are controlled and selected as appropriate to the situation, but during operation of the system, it is preferable that there is no significant variation.

For example, chirped pulses generated having a duration of approximately 100ps for a data rate of 10Gbit/s, may be passively multiplexed to form a continuous stream of pulses with the time between successive chirped pulses being substantially zero. Further, for example, where T is the nominal bit period in the optical packet, if T=10ps, 1/T= 100Gbit/s. Depending on the application, the chirped pulses may have other characteristics and in many applications the pulses in the continyous pulse stream will be spaced apart significantly. For example, for asynchronous demultiplexing, if it is desired to demultiplex, for example by taking out a data channel at a lower rate, a chirped pulse stream comprising spaced chirped pulses would preferably be used. For example, a chirped pulse stream in which each chirped pulse has a duration of 25 picoseconds, and a spacing between chirped pulses of 100 picoseconds. This arrangement has the advantage of enabling the clock to be recovered more easily using such spaced signals than with a pulse stream in which no significant gap appear between pulses.

For chirped pulse streams without significant gap between pulses, although it is not essential that the bit rate of the data source and the chirped source are the same, it is preferable that they lie close to the same nominal value, 1/T, where T is the nominal

bit period. How close the bit rate of the data source and the chirped source will lie depends on the packet length. The time within which a packet may become offset depends on the number of packets and the bit rate variation in the system.

The node 10 is configured as or includes an optical gate 12, which performs an AND gate function. The optical gate may be implemented in many different ways. For example, for ultrafast operation, the gate 12 could be a nonlinear optical device such as a fibre loop mirror (as described, for example, by Whitaker et al in Optics Letters, vol. 16, page 1840 (1991)), in which case the gate width is defined by selecting a suitable fibre length, dispersion and birefringence. Alternatively a suitable ultrafast gating device based on the nonlinearity in semiconductor optical amplifiers could be used (as described, for example, by Kang et al in the International Journal of High Speed Electronics and Systems, vol. 7, page 125 (1996)). In this case the gate width may be determined by the positioning of the amplifier in a Sagnac interferometer loop arrangement, or by the relative offset of two amplifiers in a Mach-Zehnder interferometer device. Another suitable ultrafast semiconductor-based device is the ultrafast nonlinear interferometer switch described by Hall and Rauschenbach (paper PD5, Proceedings of Conference on Optical Fiber Communication OFC'98, published by the Optical Society of America, February 1998), which has been shown to operate at a speed of 100 Gbit/s. For operation at lower speeds, for example, an optoelectronic device such as an electroabsorption modulator could be used as the gate. In that case, the incoming packet data bits must first be received by a photodetector whose output is converted to a suitable short electrical pulse to drive the modulator, and the gate width is defined by the width and amplitude of this electrical pulse. In this case, for correct operation it is necessary that the photodetector and associated electronics can fully resolve the data bits, which limits the packet data rate. The AND gate function can also be achieved by four-wave mixing (FWM) in an optical fibre or semiconductor optical amplifier. Other techniques include optical cross-correlation in a nonlinear crystal or two-photon absorption in a semiconductor.

Figures 1 and 2 illustrate how the device 8 for correcting timing fluctuations fits within the system. Chirped pulses are generated within the device at the source 32. Optical data pulses dp are generated at a remote source 30. The device 8 includes a

node 10 having first and second inputs 2, 4. The data pulse dp is received at a second input 2 of the node 10. The chirped pulse cp is received at the first input 4 of the node. When the data pulse dp is present at the second input 2 of the node 10 and a chirped pulse cp is present at the first input 4 of the node 10, the node 10 is arranged to generate an output pulse vcp at the output 6. The data pulse dp triggers the node, and operates on the chirped pulse cp arriving at the first input 4 of the node 10. The operation of the triggering data pulse dp on the chirped pulse cp through the optical AND gate 12, has the effect of selecting a segment from the chirped pulse. For example, as shown in Figure 1, with a NOLM (non-linear optical loop mirror) all-optical switch 5, the chirped pulses are input to a 50:50 coupler 7 at the input to the loop and propagate around the fibre of the loop such that they interfere constructively back at the coupler of the NOLM and are directed back to the NOLM input. However, when the amplified data pulses are introduced into the loop via a second fibre coupler (not shown), the segment of the chirped pulse which propagates with the data pulse (which is shorter in duration than the chirped pulse) experiences a nonlinear phase shift via cross-phase modulation. The nonlinearity is instantaneous (i.e. the nonlinearity responds to the time varying amplitude of the light electric field), so the data pulse does not affect the other parts of the chirped pulse. The segment is selected because the nonlinearity is instantaneous and it is only those frequencies of the chirped pulse cp that travel at the same group velocity as the data pulse within the fibre that interact with the data pulse dp. This results in only that part of the chirped pulse which has interacted with the data pulse being transmitted at the output 6 of the interferometer 5.

When the chirped pulse interferes back at the 50:50 coupler, there is now a segment of the chirped pulse which has interacted with the data pulse. As a result that segment of the chirped pulse has the differential phase shift. A differential phase shift of pi radians has the effect of directing the chirped segment that has interacted with the data pulse to the output port 6 of the NOLM.

Depending on the particular arrangement, the selected segment can have the same pulse shape, spectral quality and amplitude as the data pulse. However, this is not necessary. The optical gate can be chosen to vary any of these properties of the generated pulse. However, because the chirped pulse cp comprises a variable

frequency range, the wavelength of the selected segment is determined in accordance with where the data pulse falls within the duration of the chirped pulse. It will be understood that the selected segment will comprise a small range of discrete wavelengths corresponding to those falling within the part of the chirped pulse that has been selected, depending on the part of the chirped pulse with which the data pulse interacts.

Thus, the wavelength of the pulse 16 output from the gate 12 is dependent upon the temporal offset of the data pulse dp with respect to the start of the chirped pulse cp. This arrangement provides the advantage that regardless of the fluctuation of the arrival time of the data pulse within the duration of a chirped pulse, provided that it arrives during the presence of a chirped pulse, it will always operate on a portion of the chirped pulse to produce an output pulse vcp.

The device 8 includes a delay means 14 which subjects the output pulse from the gate to a delay which depends upon the wavelength of the output pulse, so that the output pulse arriving at a downstream node 18 is substantially jitter free. The delay means 14 includes a dispersion compensation medium such as a length of dispersion compensated optical fibre or a grating. The optically dispersive medium is selected to have a dispersion profile matching the wavelength profile of the chirped pulse. For example, for a chirped pulse having a wavelength profile whose wavelength varies linearly over time during the duration of the pulse, a dispersion compensating fibre will be selected bearing in mind the wavelength variation in the chirped pulse, wherein the lower frequency components travel slower in the fibre than the higher frequency components. The dispersion compensated fibre is selected, so that after an optimum fibre length, which can be determined either theoretically or experimentally, all wavelength components of the chirped pulse will overlap in time, so that they arrive at the remote detector 18 at the substantially the same time.

It will be appreciated that the different wavelengths forming in a pulse having been transmitted along a non-dispersion compensated length of optical fibre will arrive at different times at a detector, since each wavelength is subject to a different degree of dispersion. The effect of subjecting the output pulse vcp to appropriate dispersion compensation is to temporally “squeeze” the generated pulse, so that regardless of its constituent wavelengths, all constituent wavelengths of the pulse will arrive at a detector at the same time.

The optimum dispersion compensating fibre length thus has the effect of compressing the temporal duration of all wavelength components within the generated pulse. The optimum dispersion compensation is determined by selecting the fibre length to give the shortest temporal duration of output pulse. In practice, this could be calculated theoretically from the fibre and chirped pulse parameters. Alternatively, the correct fibre length can be determined by coupling the output to a variety of dispersion compensating fibres of varying lengths and by selecting the length that provides the shortest output pulse.

In this way, the dispersion compensation means 14 is selected, for example by varying the length of dispersion compensated fibre, so that the arrival time of the pulse output can be set and the pulse duration can be minimised regardless of the wavelength of the pulse output by the gate. Thus, the advantage of this arrangement is that any pulse outputted by the gate will arrive after a predetermined time at the downstream node 18.

It is thus appreciated, that according to the present invention, the pulse arriving at the node 10 may suffer severe jitter, yet pulses arriving at the downstream node 18 arrive substantially jitter free. In this way the timing fluctuations suffered by data pulses are corrected.

Figure 4 shows a device for correcting for timing fluctuations suffered by data pulses according to a second embodiment of the present invention. In particular, Figure 4 shows how a plurality of pulses which may have suffered timing fluctuations are corrected for timing fluctuations so that they arrive at the downstream node 18 equally spaced in time. The device shown in Figure 4 works according to the same principle as described with respect to Figures 1 and 2. According to Figure 4 a plurality of optical data pulses dp1, dp2, dp3 produced by data source 30, reach a remote node 10 having suffered timing fluctuations. For example dp1 and dp2 are temporally displaced by a time delta t12, and dp2 and dp3 are temporally displaced by a time delta t23. Each data pulse dp1, dp2, dp3 in the node 10 operates on respective chirped pulses cp1, cp2, cp3. The time between each successive generated chirped pulse may be substantially zero. In cases where there is spacing between successive chirped pulses, the spacing is equal. The output of the node comprises three pulses 160, 162, 164, lambda1, lambda2 and lambda3, so that

although the pulse shape of these pulses is the same as their corresponding data pulses, their wavelength or wavelength range depending on the wavelength profile of the chirped pulse, as discussed above is dependent upon the temporal offset of each pulse with respect to the chirped pulse.

After leaving the node 10 pulses 160, 162, 164: lambda1, 2 and 3, are nevertheless still subject to time fluctuations delta t12 and delta t23 with respect to each other. The delay means 14 preferably includes appropriate dispersion compensation means 14 which disperses pulses 160, 162, 164 in accordance with their wavelengths respectively, so that the pulses 180, 182, 184, having wavelengths lambda1,2 and 3, respectively, arrive equally spaced in time at the remote downstream node 18.

Figure 5 shows, in the solid lines, a plurality of chirped pulses. The frequency characteristic of the pulses is that of a saw tooth with respect to time. Figure 5 depicts chirped pulses that are linearly chirped. That is over the period of the pulse the wavelength, and hence, frequency of the pulse increases linearly. However, provided the dispersion means are compensated appropriately, there is no reason why non-linearly chirped pulses may not be used. It will be appreciated that, in order to compensate for a nonlinearly chirped pulse, the dispersion means should have an opposite nonlinear characteristic.

The dotted lines on Figure 5 gives a schematic indication of the amplitude of successive chirped pulses. A succession of chirped pulses are generated according to the method described below. The pulses are preferably square shaped, having a sharp rise time and fall time. The duration of the pulses T is chosen to be appropriate for the incoming data rate (1/T) e.g. 25ps for a data rate of 40Gbit/s. The frequency chirp is preferably linear across the chirped pulse with a frequency variation of 600GHz for a 25ps chirped pulse.

However, it is envisaged that, depending on the data rate of the incoming data pulses and the application, chirped pulses having other characteristics would also be used.

Chirped pulses as such are known of course. For example, Uchiyama K, Takara H, Morioka T, Kaweanishi S and Saruwatari M, Electronics Letters. Vol 32, No. 21, 10th October 1996, discloses the use of chirped pulses for the different application of

converting TDM signals (time division multiplexing) to WDM signals (wavelength division multiplexing).

Figure 6 shows one example of how chirped pulses are generated. A mode locked laser is used to generate optical pulses at 10GHz at a predetermined wavelength. The laser output is fed into an appropriate length of non-linear optical fibre with normal dispersion, such as Sumitomo fibre 788-6902-03. Whilst propagating in the length of non-linear optical fibre the pulses undergo self phase modulation which has the effect of broadening the frequency spectrum of the light within each pulse by an amount deltav. The frequency spectrum of the chirped pulses can be controlled by selecting characteristics of the non-linear fibre used, in particular its length and/or composition and/or construction. Further, the input power to the fibre can also be varied to change the nonlinear broadening effect, since the broadening is proportional to the peak power of the input optical pulse.

Whilst undergoing frequency spectrum broadening, the duration T of the pulses is controlled by the dispersion of the fibre. The duration T can be increased by dispersing the spectrum broadened pulses into the length of non-linear optical fibre. Whilst propagating in the length of ordinary fibre the pulses undergo group velocity dispersion. This has the effect of increasing the duration of the pulses by an amount deltat. The amount of increase of duration, deltat, is controlled by the dispersion experienced by the pulse which is controlled by varying the length and/or the composition of the non-linear optical fibre. The duration is chosen depending on the particular application. This will depend for example, on the data rate of the data pulses. For example, for a data rate of 10GHz, a duration for the chirped pulses of 100ps is preferred.

The output from the lengths of non-linear optical fibre are chirped pulses broadened both in terms of their frequency spectrum, deltav, and their duration T, by amount deltat.

Depending on the application, two subsequent modulation stages can be carried out, for example, to further shape the chirped pulses. Electroabsorption modulation removes the edges to reduce the rise time of the pulses. In a further modulation stage, the intensity of the pulses is modulated. In particular, the peaks of the chirped

pulse are selectively attenuated. This has the effect of flattening the top of each chirped pulse. This can be done for example, using a lithium niobate modulator. It can be understood, that by using the method described above, the characteristics of the chirped pulses can be varied. For example, the pulse duration can be varied by selecting the characteristics of the ordinary fibre used, in particular, its length and composition.

Figure 7 shows a regenerator 40 including a device 8 shown within the dotted lines, according to the first embodiment of the present invention. The device 8 for correcting for timing fluctuations suffered by data pulses has application as a pre-stage for a regenerator 40, such as those regenerators disclosed in our pending application GB99/01159. As can be seen from Figure 7, the output from the device 8, which comprises equally spaced pulses T of differing wavelengths lambda1, lambda 2 and lambda 3 etc, is input to a further node 42 comprising a further AND-gate 42. A local optical clock stream 44 is also input to the AND-gate 42. The pulses lambda 1, 2 and 3, operate on the clock pulses to generate regenerated optical pulses lambda t0 having the same pulse shape, spectral quality, amplitude and timing stability as the local source 44 of the stream above. Because the input pulses of lambda1, 2 and 3 have equal temporal spacings, it greatly reduces the switching window requirement at node 42 to accommodate the effects of jitter and maintain an acceptable bit-error rate (BER). For example, with a switching rate of 10GHz and a window width of 75ps, if the jitter is reduced from 3ps rms to 1.8ps rms with the chirped pulse retimer then the BER improves from 1 in 10^6 to 1 in 10^{12} respectively.

The device of the present invention when incorporated as a pre-stage to a regenerator further reduces the number of gates necessary to achieve robust regeneration. Thus, the apparatus necessary to correct for timing fluctuations and retime and regenerate a data signal or stream of data signals is simplified. Figure 6 depicts a regeneration device incorporating an all optical asynchronous regenerator as disclosed in our pending unpublished application GB A 9808491. A regenerator of this type must be designed to regenerate correctly each data signal regardless of the phase difference between the data signal and the local clock. An error free regeneration cannot be completely guaranteed using a single gate. It has been found that even for an ideal

square switching window having a duration equal to the period of the data pulses, there exists a small chance that the data pulse falls at the edge of the switching window. If a data pulse were to fall directly between two switching windows, there is a chance that it may be lost. To overcome this problem, our pending application GB A 9808491 discloses a regenerator comprising two or more gates, in which the switching windows are provided so that each gate is able to regenerate correctly a data pulse falling within a restricted phase shift range, however, the two or more gates together span the entire possible phase shift range of zero to two pi. By monitoring the gate outputs, the regenerator selects a correctly regenerated output from one of the gates in each time slot. The simplest multiple gate regenerator is a dual gate asynchronous burst regenerator. However, although the bit error rate of the dual gate regenerator is lower than for the single gate regenerator, it has been found that despite adding complexity to the system, a quad gate regenerator provides a more robust solution. A quad gate regenerator's performance is more robust than a dual gate regenerator because the quad gate regenerator can tolerate a higher level of jitter. The reason for this is that, in the case of the quad gate regenerator, the local clock pulses modulated by a correctly selected gate are positioned further from the edges of the gate window for all possible phase shifts. The disadvantage of the quad gate regenerator, however, is that it requires more gates, and is thus more complex. However, if the timing fluctuation correction device of the present invention is added to the front end of a regenerator, as shown in Figure 6, jitter is compensated for as discussed above, prior to regeneration. Thus, if the timing fluctuation correction device of the present invention is added to a regenerator, robust regeneration can be achieved with a dual gate regenerator. This arrangement reduces the total number of gates necessary for regeneration and greatly simplifies the regenerator apparatus whilst maintaining a high level of robust performance.

Figure 8 depicts the preferred dual gate bit asynchronous optical packet regenerator in which the timing fluctuation correction device of the present invention may be incorporated. The data bits in the incoming packet are used to control the opening of two gates, G1 and G2. A data bit with value 1 ('mark') causes each of the two gates to open for a fixed time duration (the gate window), otherwise the gates remain closed. It is preferable, though not essential, that the widths of the time window for

gates G1 and G2 are equal. The output from the local clock (a continuous free-running source of optical RZ pulses at a repetition frequency nominally equal to the packet bit rate $1/T$) is applied to the inputs of the two gates, one of these inputs being delayed relative to the other by an amount $T/2$. Since the phase θ of the local clock pulses relative to the packet data bits has an arbitrary and unknown value in the range $0 \leq \theta < 2\pi$, it is necessary that the gate window widths are chosen so that, whatever the value of θ, the clock pulses will be correctly modulated by at least one of the two gates. In the case that the window widths for gates G1 and G2 are equal, the window width W must therefore lie in the range $T/2 < W < T$. The lower limit ensures that at least one clock pulse will be modulated at any value of θ, whilst the upper limit comes from the requirement that no more than one clock pulse may pass though the gate whilst the window is open. These upper and lower limits on W apply strictly in the case that the incoming data pulses and local clock pulses are sufficiently narrow that, on the time scale of a bit period, they may be represented by delta impulses. When finite pulse widths are taken into account the acceptable range of window widths is somewhat narrower than $T/2 < W < T$. At present, it will be assumed that the data pulses and local clock pulses are short pulses, and for the remainder of this sub-section it is taken that $W = 3T/4$ for both gates.

It should be noted at this point, with reference to Figure 7, that there is an alternative and equally valid configuration in which the $T/2$ delay line is removed from the input port A of one of the gates, and placed instead at the control port C of one of the gates. The operation of the regenerator is very similar in this case, and the predicted performance described later is the same. Throughout the remainder of this description, the configuration will be assumed to be that in which the packet data bits are connected directly to the control ports of the gates, and the input ports have certain differential delays (as illustrated in Figure 7 for a dual-gate regenerator).

The optical gates may be implemented in different ways, and may be the same as those discussed above with respect to the retiming device of the present invention. For example, for ultrafast operation, the gate could be a nonlinear optical device such as a fibre loop, in which case the gate width is defined by selecting suitable fibre length, dispersion and birefringence. Alternatively a suitable ultrafast gating device based on the nonlinearity in semiconductor optical amplifiers could be used. In this case the gate width may be determined by the positioning of the amplifier in a Sagnac

interferometer loop arrangement, or the relative offset of two amplifiers in a Mach-Zehnder interferometer device. Another suitable ultrafast semiconductor-based device is an ultrafast nonlinear interferometer switch, which has been shown to operate a speed of 100 Gbit/s. For operation at lower speeds an optoelectronic device such as an electroabsorption modulator could be used as the gate. In that case, the incoming packet data bits must first be received by a photodetector whose output is converted to a suitable short electrical pulse to drive the modulator, and the gate width is defined by the width and amplitude of this electrical pulse. In this case, for correct operation it is necessary that the photodetector and associated electronics can fully resolve the data bits, which limits the packet data rate.

Figure 9 shows a sequence of timing diagrams that illustrate the operation of the dual-gate regenerator. The packet data bits (an example sequence 11101 is shown) arrive at the control ports of the gates G1 and G2, and each 'mark' causes the gates to open for a time $3T/4$. The diagrams (i–iv) illustrate various values of θ, the phase of the local clock relative to the incoming packet data bits. It is convenient to write the gate width W and phase angle θ as normalised quantities, thus: $\overline{W} = W/T$ and $\bar{\theta} = \theta/2\pi$. Diagram (i) illustrates the case $0 \le \bar{\theta} \le \overline{W} - 1/2$, in which the outputs from both gates G1 and G2 are clock pulses that have been correctly modulated by the incoming data bits. Diagram (ii) illustrates the case $\overline{W} - 1/2 < \bar{\theta} < 1/2$, in which the output from gate G1 (but not G2) are clock pulses that have been correctly modulated by the incoming data bits. Diagram (iii) illustrates the case $1/2 \le \bar{\theta} \le \overline{W}$, in which again the outputs from both gates G1 and G2 are correctly modulated. Diagram (iv) illustrates the last possibility, $\overline{W} \le \bar{\theta} < 1$, in which the output from gates G2 (but not G1) is correctly modulated.

Returning to Figure 7, the components shown to the right-hand side of the two gates are used to attempt to select in each time slot whichever gate output gives a regenerated packet with the minimum of bit errors. One technique, shown in Figure 7, is to make the selection in each time slot on the basis of a comparison of the total optical energy emerging from each gate, integrated over the duration of the packet. If the phase angle θ is such that the output from a gate consists of correctly modulated clock pulses then the total optical energy measured at the output of the gate, integrated over the duration of the packet, will be maximum (in effect, it is a

measure of the number of 'marks' appearing in the regenerated data packet). However if θ is such that the clock pulses arrive at the gate at a time outside the gate window, then the energy transmitted by the gate will be zero or small. The circuit shown in Figure 7 therefore makes these energy measurements and the result of the comparison is used to set the optical switch *S*, (for example, an optoelectronic device such as a lithium niobate switch) which performs the physical selection. The detectors, D1 and D2, are followed by electronic integrators I1 and I2, each of which provide a voltage proportional to the energy of the regenerated packet emerging from gates G1 and G2, respectively, in each time slot. The comparator C produces a digital output according to whether or not the signal from D1 exceeds that from D2. The global packet-level clock signal, synchronised to the time guard band between packets, is used to reset the integrators and also to clock the D-type flip-flop DT. This ensures that the switch S changes over only during the guard band, so as to avoid corrupting a packet. Notice that the detectors, switch and associated electronics operate at the packet rate (not the data bit rate) with a response time on the order of the width of the time guard band (which may be on the time scale of ~1 ns).

An alternative method of selecting the most appropriate gate output in each time slot may be to perform a bit-error measurement on the whole or part of the packet that emerges from each gate. For example, a test pattern could be incorporated as part of each packet, and this pattern would be received and any bit errors detected and counted in each time slot at the output of each gate. In a given time slot the output having zero or the least number of bit errors would be selected.

The optical delays (labelled L and $L+\Delta T/2$ in Figure 7) between the outputs of the gates and the selection switch S are used to allow sufficient time for the circuitry and switch S to operate before the packets arrive at the switch. Typically the delay L will be slightly less than one time slot in duration. Optionally, as shown in Figure 7, the optical delay between the output of gate G1 and the switch S may be made slightly longer (by an amount $T/2$) than the delay between the output of gate G2 and the switch. The purpose of doing this is to compensate for the delay of $T/2$at the input of gate G2, thus equalising the delay of both optical paths from the clock source to the output of the selector switch S. One benefit of doing this is that all the regenerated packets are then in precise bit synchronism with each other and with the

local clock, and as mentioned earlier, the local clock may therefore be used as a continuous and regular source of pulses for use in subsequent digital optical processing stages. A further important benefit of equalising the delay in this way is to reduce the problem of 'packet slippage' in a large network.

Figure 10 shows a device for quantifying the amount of jitter experienced by an optical data pulse in an optical transmission system. The device shown in Figure 10 differs from that shown in Figure 1 in that it is not necessary to include a delay means. The device functions in the same way as that shown in Figure 1, except that the output of the AND gate is fed to a wavelength detector 18. It is not necessary to feed the output of the AND gate to a delay means.

The device 8 shown in Figure 10 for quantifying an amount of jitter experienced by an optical data pulse includes a chirped pulse source 32 for generating chirped pulses. The chirped pulses have a duration T, and have a wavelength which varies in a predetermined monotonic manner over the duration T of the chirped pulse. The significance of the monotonic variation is explained below. The source 32 provides a source of RZ chirped pulses which is continuously free-running. It is independent from the data pulse source 30. The chirped pulse source 32 can be either one which is part of the node, or one that is local to one node, but not part of the node, or remote from the node. Where the chirped pulse source is remote from a node a single source could be shared between multiple nodes, although a source may be shared between several nodes and still be part of one of the nodes.

Figure 5 shows the frequency characteristics of the chirped pulses and Figure 6 outlines the generation of the chirped pulses. These aspects are discussed below with respect to the device of Figure 10 for quantifying the amount of jitter experienced by a data pulse.

The period of the chirped pulses is controllable. Also, the frequency distribution which makes up the chirped pulses is controllable. The period of the chirped pulses is selected for example depending on the data rate of the data pulses input to the device at the node, or the switching rate at which the node in the device is operating. The frequency distribution is selected depending on, for example, the sensitivity of a detector 18. For example, the chirped pulses generated as shown in Figure 5 and 6 have a duration T of 25ps, and have a frequency distribution from 0 to 600 GHz.

Depending on the particular situation, the period and frequency distribution are controlled and selected as being appropriate to the situation, but during operation of the system, it is preferable that there is no variation.

For example, chirped pulses may be generated having a duration of approximately 100ps for a data rate of 10Gbit/s, and may be passively multiplexed to form a continuous stream of pulses. Thus, the time between successive chirped pulses in these examples is substantially zero. It is of course, not essential for there to be no interval between the pulses. Further, for example, where T is the nominal bit period in the optical packet, if $T=10ps$, $1/T= 100Gbit/s$. Depending on the application, the chirped pulses may have other characteristics. For example, for asynchronous demultiplexing, if it is desired to demultiplex, for example by taking out a data channel at a lower rate, a chirped pulse stream comprising spaced chirped pulses may be used. For example, a chirped pulse stream in which each chirped pulse has a duration of 25 picoseconds, and a spacing between chirped pulses of 100 picoseconds. This arrangement has the advantage of enabling the clock to be recovered more easily using such spaced signals than with a continuous stream without a significant interval between pulses.

For chirped pulse streams without significant gap between pulses, although it is not essential that the bit rate of the data source and the chirped source are the same, it is preferable that they lie close to the same nominal value, 1/T, where T is the nominal bit period. How close the bit rate of the data source and the chirped source will lie depends on the packet length. The time within which a packet may become offset depends on the number of packets and the bit rate variation in the system.

The node 10 is configured as or includes an optical gate 12, which performs an AND gate function. The optical gate may be implemented in many different ways as discussed above with reference to the device for correcting for timing jitter.

Figure 10 illustrates how the device 8 for quantifying the amount of jitter experienced by an optical data pulse fits within the system. Chirped pulses are generated within the device at the source 32. Optical data pulses dp are generated at a remote source 30. The device 8 includes a node 10 having first and second inputs 2, 4. The data

pulse dp is received at a second input 2 of the node 10. The chirped pulse cp is received at the first input 4 of the node. When the data pulse dp is present at the second input 2 of the node 10 and a chirped pulse cp is present at the first input 4 of the node 10, the node 10 is arranged to generate an output pulse at the output 6. The data pulse dp triggers the node, and operates on the chirped pulse cp arriving at the first input 4 of the node 10. The first and second inputs 2, 4 and the output 6 of the node define a gate 12. The gate 12 performs an AND gate function. The operation of the triggering data pulse dp on the chirped pulse cp through the optical AND gate 12, has the effect of selecting a segment from the chirped pulse. For example, as shown in Figure 1, with a NOLM (non-linear optical loop mirror) all-optical switch 5, the chirped pulses are input to a 50:50 coupler 7 at the input to the loop and propagate around the fibre of the loop such that they interfere constructively back at the coupler of the NOLM and are directed back to the NOLM input. However, when the data pulses are introduced into the loop via a second fibre coupler (not shown), the segment of the chirped pulse which propagates with the data pulse (which is shorter in duration than the chirped pulse) experiences a nonlinear phase shift via cross-phase modulation. The nonlinearity is instantaneous (i.e. the nonlinearity responds to the time varying amplitude of the light electric field), so the data pulse does not affect the other parts of the chirped pulse. The segment is selected because the nonlinearity is instantaneous and it is only those frequencies of the chirped pulse cp that travel at the same group velocity as the data pulse within the fibre that interact with the data pulse dp. This results in only that part of the chirped pulse which has interacted with the data pulse being transmitted at the output of the interferometer.

When the chirped pulse interferes back at the 50:50 coupler, there is now a segment of the chirped pulse which has interacted with the data pulse. As a result that segment of the chirped pulse has the differential phase shift. A differential phase shift of pi radians has the effect of directing the chirped segment that has interacted with the data pulse to the output port of the NOLM.

Depending on the particular arrangement, the selected segment can have the same pulse shape and amplitude as the data pulse. However, this is not necessary. The optical gate can be chosen to vary any of these properties of the generated pulse.

However, because the chirped pulse cp comprises a variable frequency range, the wavelength of the selected segment is determined in accordance with where the data pulse falls within the duration of the chirped pulse. It will be understood that the selected segment will comprise a small range of discrete wavelengths corresponding to those falling within the part of the chirped pulse that has been selected, depending on the part of the chirped pulse with which the data pulse interacts.

Thus, the wavelength of the pulse 16 output from the gate 12 is dependent upon the temporal offset of the data pulse dp with respect to the chirped pulse cp. This arrangement provides the advantage that regardless of the fluctuation of the arrival time of the data pulse, provided that it arrives during the presence of a chirped pulse, it will always operate on a portion of the chirped pulse to produce an output pulse whose wavelength is indicative of the amount of jitter experienced by the data pulse. In order to quantify the amount of jitter experienced by the optical pulse, the pulse 16 output from gate 12 is fed to a wavelength detector 18. The detector may, for example, be a ccmmercially available optical spectrum analyser. The optical spectrum analyser, depending on the type, includes an input fibre, slits on which the light whose wavelength or wavelengths is to be determined is incident. The slits cause the light to interfere. Disposed behind the slits is some imaging optics and a rotatable Bragg diffraction grating. The Bragg diffraction grating disperses the wavelength components of the incident light. Which wavelength is dispersed will depend on the angle at which the Bragg diffraction grating is rotated to. Thus, by measuring the angles at which light is dispersed to by the Bragg diffraction grating, the wavelength of the input light can be determined. The detector 18 is selected to be able to detect over the wavelength range of the chirped pulse. The detector 18 is selected to be able to detect over the wavelength range of the chirped pulse. The device for quantifying the amount of jitter experienced is calibrated so that for a given jitter, a given wavelength segment of the chirped pulse will be output from the gate 12. The detector 18 detects the output pulses and measures their respective wavelengths. As mentioned above, the chirped pulses have a duration T, and have a wavelength which varies in a predetermined monotonic manner over the duration T of the chipred pulse. It is necessary to be able to establish how the wavelength varies over the duration of the chirped pulse in order to quantify the amount of jitter experienced by a data pulse. Also it is necessary that the wavelength varies monotonically, i.e. it either increases

or decreases over the duration of the pulse. This excludes the possibility that a data pulse having experienced an amount of jitter tj triggers the AND gate to output a pulse having a wavelength lambda tj, that a second data pulse having experienced a different amount jitter, also triggers the AND gate to output a pulse having wavelength lambda tj. Thus, for each amount of jitter experienced, the AND gate is triggered to output a pulse having a wavelength indicative of each amount of jitter, This is the consequence of the chirped pulse having a wavelength which varies monotonically over the duration T of the chirped pulse input to the AND gate. Thus, by comparing the measured wavelength of the pulse detected at detector 18 with the calibrated measurements, the amount of jitter suffered by the pulse is quantified.

Having determined the amount of jitter suffered by the optical pulses, this can be used as a diagnostic tool to identify causes of jitter in the optical system. For example, a systematic jitter may be indicative of a localised temperature disturbance or mechanical stress in the system. Thus, the measure of jitter is used to provide a control signal to control a feed back loop operative on one or more elements of the transmission system to reduce the amount of timing jitter.

The device for quantifying the amount of jitter may include an optically dispersive medium 14 which subjects the output pulse from the gate to a delay which depends upon the wavelength of the output pulse, so that the output pulse arriving at the remote detector 18 is substantially jitter free on arrival at the detector 18. The optically dispersive medium 14 includes a dispersion compensation medium such as a length of dispersion compensated optical fibre or a grating. The optically dispersive medium is selected to have a dispersion profile appropriate for the wavelength profile of the chirped pulse. For example, for a chirped pulse having a wavelength profile whose wavelength varies linearly over time during the duration of the pulse, a dispersion compensating fibre will be selected bearing in mind the wavelength variation in the chirped pulse, wherein the lower frequency components travel slower in the fibre than the higher frequency components. The dispersion compensated fibre is selected, so that after an optimum fibre length, which can be determined either theoretically or experimentally, all wavelength components of the chirped pulse will

overlap in time, so that they arrive at the remote detector 18 at the substantially the same time.

It will be appreciated that the different wavelengths comprised in a pulse having been transmitted along a non-dispersion compensated length of optical fibre will arrive at different times at a detector, since each wavelength is subject to a different degree of dispersion. The effect of subjecting the generated pulse to appropriate dispersion compensation is to temporally "squeeze" the generated pulse, so that regardless of its constituent wavelengths, all constituent wavelengths of the pulse will arrive at a detector at the same time.

The optimum dispersion compensating fibre length thus has the effect of compressing the temporal duration of all wavelength components within the generated pulse. The optimum dispersion compensation is determined by selecting the fibre length to give the shortest temporal duration of output pulse. In practice, this could be calculated theoretically from the fibre and chirped pulse parameters. Alternatively, the correct fibre length can be determined by coupling the output to a variety of dispersion compensating fibres of varying lengths and by selecting the length that provides the shortest output pulse.

In this way, the dispersion compensation means 14 is selected, for example by varying the length of dispersion compensated fibre, so that the arrival time of the pulse output can be set and the pulse duration can be minimised regardless of the wavelength of the pulse output by the gate. Thus, the advantage of this arrangement is that any pulse outputted by the gate will arrive after a predetermined time at the detector 18.

It is thus appreciated, that the pulse arriving at the node 10 may suffer severe jitter, yet pulses arriving at the detector 18 arrive substantially jitter free. In this way the amount of jitter experienced by a data pulse is quantified and corrected.

There are two main causes of bit errors that may occur in the process of regenerating a packet using the bit-asynchronous regenerator. The first cause is jitter, as identified above, in the arrival time of the incoming packet data bits. The second main cause of bit errors is errors in the process used to select the output from one of the gates in each time slot. Thus, it will be understood, that if jitter and other timing errors can be

corrected by using the device of the present invention prior to regeneration, bit error rates for regeneration will be greatly improved.

CLAIMS

1. A method of correcting for timing jitter of an optical data pulse in an optical transmission system, the method including:

i) generating a chirped optical pulse containing a spread of wavelengths;

ii) applying the chirped pulse to one input (4) of an optical AND gate (10) in synchronism with the unjittered arrival time of the data pulse:

iii) applying the optical data pulse to a second input (2) of the optical AND gate to trigger the AND gate and to produce at the output (6) of the AND gate (10) an output optical pulse having a wavelength determined by the amount of jitter experienced by the data pulse with respect to the unjittered arrival time; and thereafter

iv) passing the optical output pulse through a suitable optically dispersive medium (14) so that the output pulse is correctly retimed to compensate for the jitter of the optical data pulse.

2. A method as claimed in claim 1, wherein the chirped optical pulse is one of a stream of pulses, and wherein the data pulse is one of a clocked stream of data pulses, the stream of chirped pulses being synchronized with the clock of the data pulse stream.

3. A method of correcting for timing jitter of optical pulses in an optical transmission system, which method includes using the optical pulses to trigger an optical AND gate (10), which also receives chirped optical pulses, to produce output optical pulses having a wavelength determined by the amount of jitter in the respective optical trigger pulse, and thereafter passing the optical output pulses through an optically dispersive medium (14), so that the different wavelength output pulses are temporally shifted in accordance with their wavelength, so that after passage through the dispersive medium (14) the output pulses are correctly retimed.

4. A method as claimed in claim 2 or claim 3, wherein said chirped pulses have a duration T, and said wavelength of said chirped pulses varies in a predetermined monotonic manner over said duration T of said chirped pulses.

5. A method as claimed in claim 2 or claim 3, wherein if the duration of the chirped pulses is T, the data rate of the chirped pulses is 1/T..

6. A device for correcting for timing jitter of optical pulses in an optical transmission system, said device including an optical AND gate (10) having an output and first (4) and second (2) inputs, the first input of the AND gate (10) being connected to a source of chirped optical pulses (32), wherein when one of said optical pulses is received at the second input (2) while one of the chirped pulses is present at the first input (4), the AND gate (10) is triggered to produce an output optical pulse whose wavelength is determined by the amount of jitter in the optical trigger pulse, said device further including an optically dispersive medium (14) having a dispersion profile appropriate for the wavelength profile of said chirped pulses, through which said output pulses pass, so that different wavelength output pulses are temporally shifted in accordance with their wavelength, so that after passage through the dispersive medium said output pulses are correctly retimed.

7. A regenerator including a device according to claim 6, including:
a second optical AND gate (42) disposed to receive said output pulses and local clock pulses, wherein said AND gate (42) is arranged so that said output pulses operates on said local clock pulses to produce regenerated pulses having a wavelength determined by said local clock pulse and independent of the wavelength of the pulse received at the second AND gate (42).

8. Use of a device as claimed in claim 7 to correct for jitter suffered by optical pulses.

ABSTRACT

Communications Network

A device and method for correcting for timing jitter of an optical data pulse in an optical transmission system. During transmission data pulse may suffer jitter. Its arrival time at a node may be temporally offset from its predicted arrival time. Data pulses are timed so that they may be received at a detector disposed downstream of said node at a predetermined time. The device including a source of chirped optical pulses and a node, which has a first input arranged to receive a chirped optical pulse, the node having a second input arranged to receive a data pulse. The node including an optical gate arranged to generate an output pulse in response to said first pulse and said data pulse received at said first and second inputs, respectively, having a wavelength dependent upon the time t at which said data pulse is received at said second input. The device further including an optically dispersive medium after passage through which, the output pulses are correctly retimed.

Figure 1

A25755

09/936049

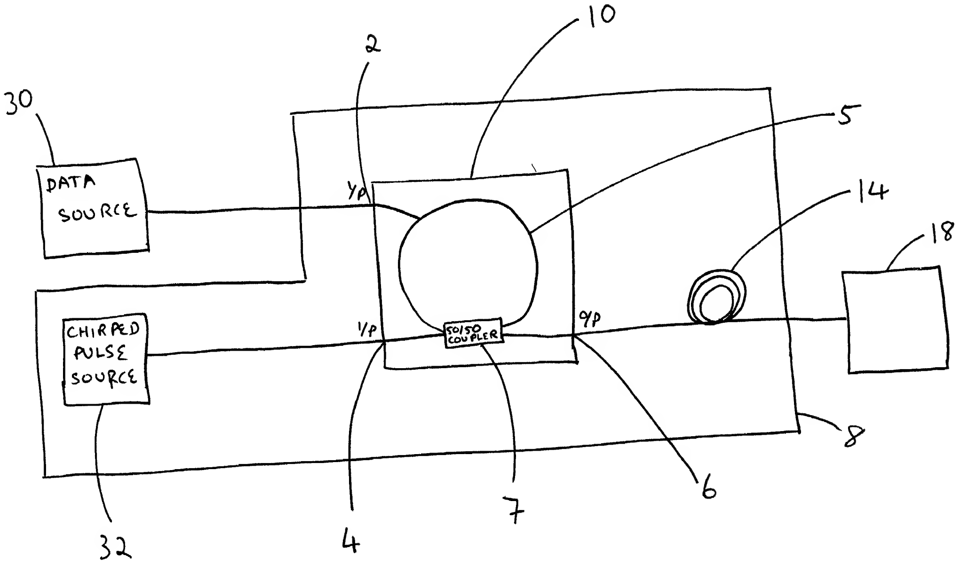


Figure 1

09/936049

Figure 2

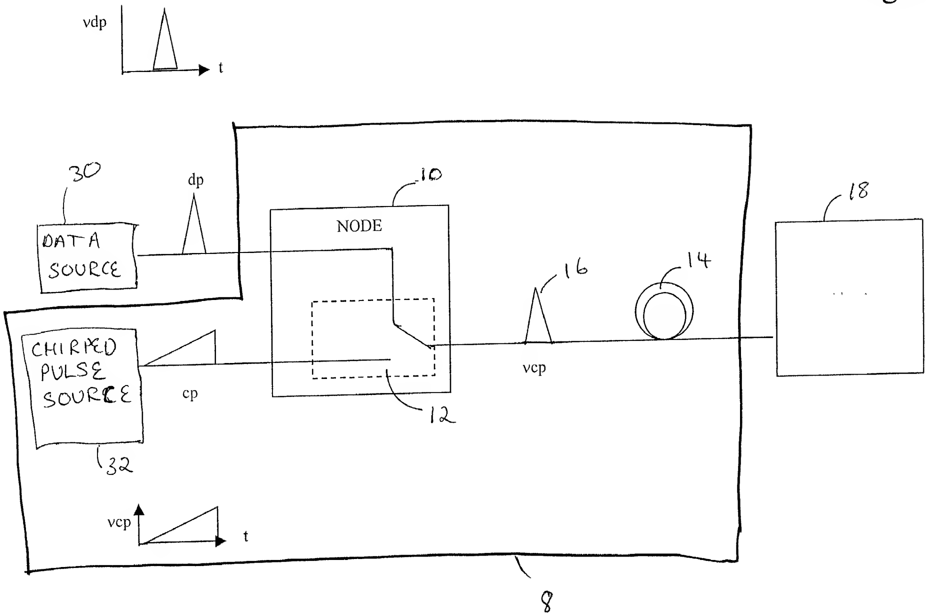


Figure 3

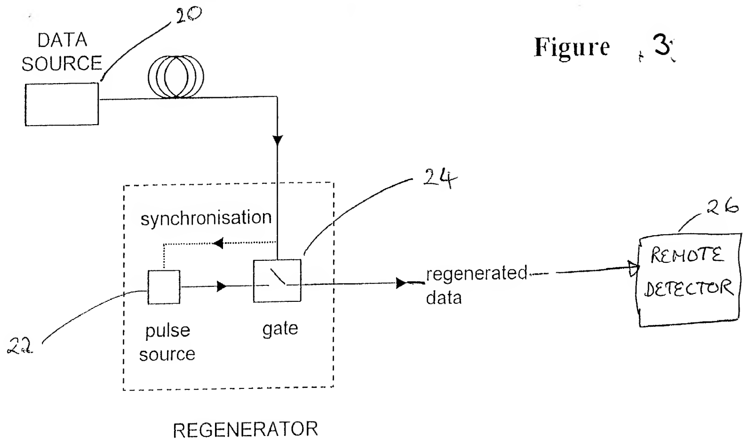
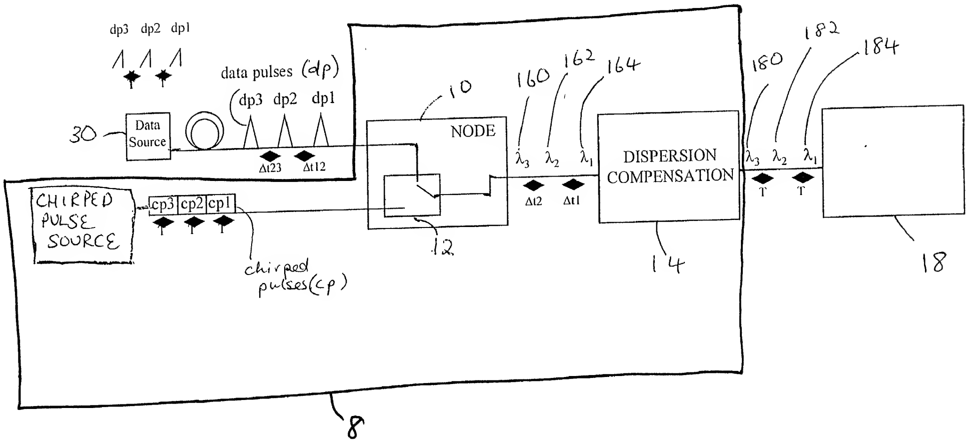
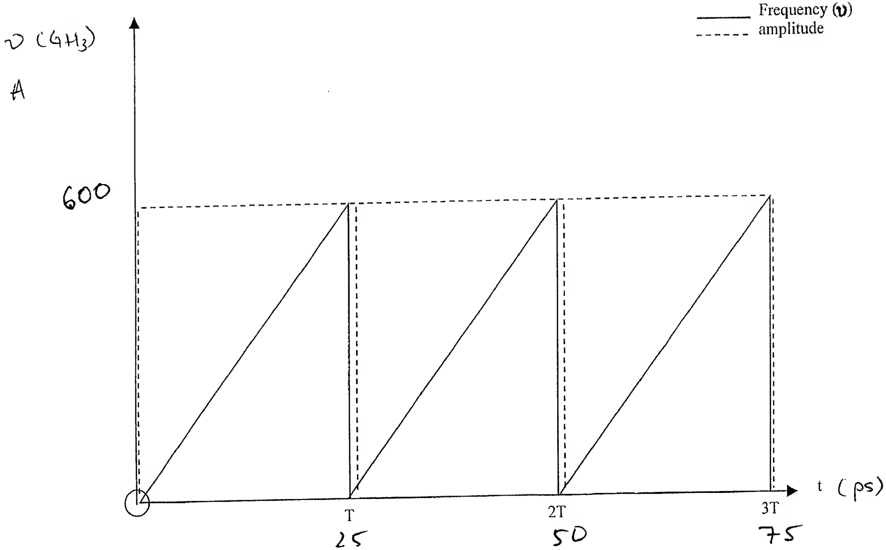

DATA SOURCE
20
synchronisation
pulse source
gate
24
22
regenerated data
26
REMOTE DETECTOR
REGENERATOR

Figure 4



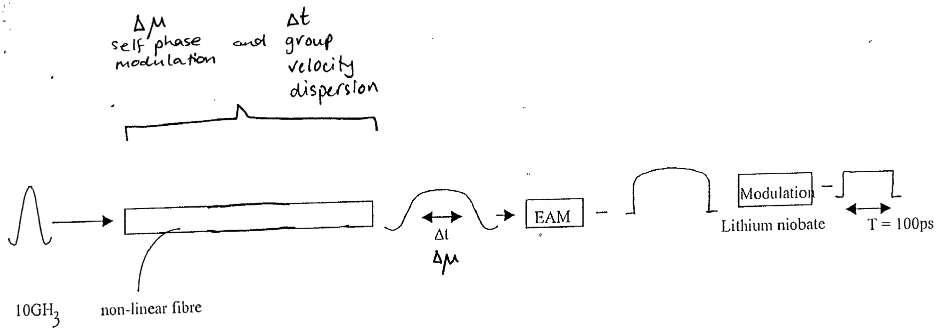
09/936049

Figure 5



09/936049

Figure 6


Δμ self phase modulation and Δt group velocity dispersion
EAM
Δt
Δμ
Modulation
Lithium niobate
T = 100ps
10GH3
non-linear fibre

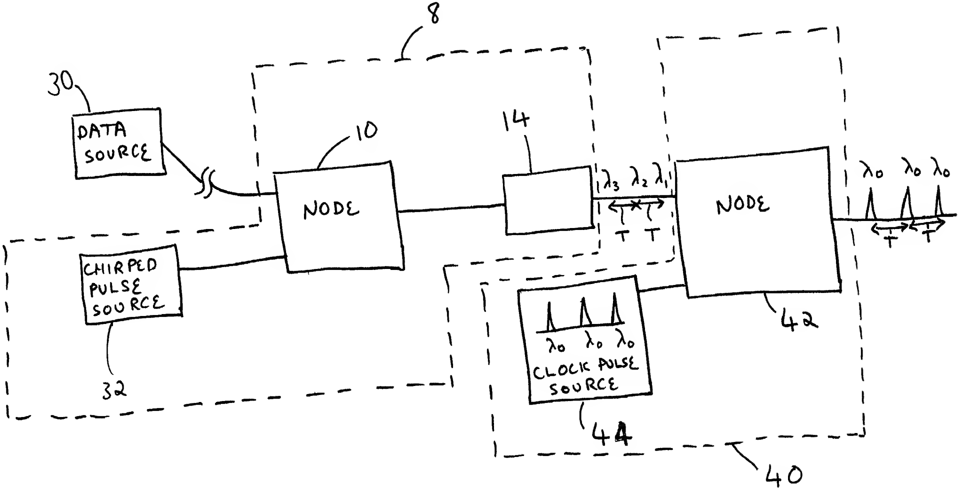
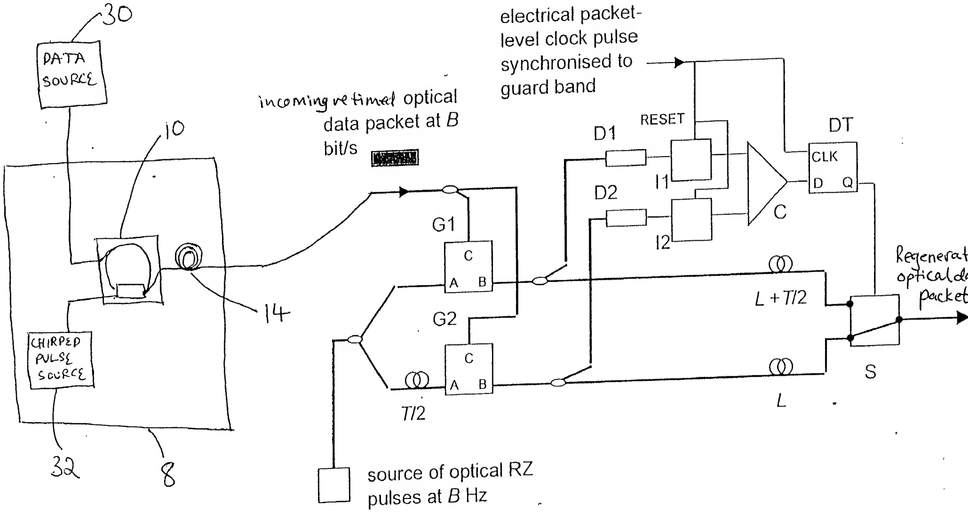

8
30
DATA SOURCE
10
NODE
14
λ_3 λ_2 λ_1
T T
NODE
λ_0 λ_0 λ_0
T T
CHIRPED PULSE SOURCE
32
λ_0 λ_0 λ_0
CLOCK PULSE SOURCE
42
44
40

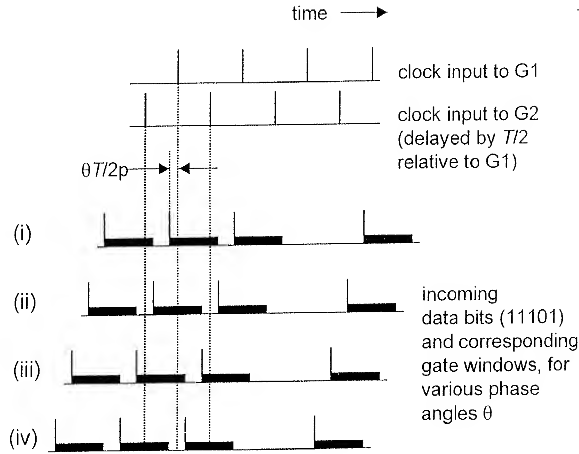
Figure 7

Figure 8



30
DATA SOURCE
10
CHIRPED PULSE SOURCE
14
32
8
incoming retimed optical data packet at B bit/s
electrical packet-level clock pulse synchronised to guard band
RESET
D1
D2
I1
I2
C
DT
CLK
D
Q
G1
G2
C
A
B
T/2
L + T/2
L
S
Regenerated optical data packet
source of optical RZ pulses at B Hz

Figure 9


time
clock input to G1
clock input to G2 (delayed by T/2 relative to G1)
θT/2p
(i)
(ii)
(iii)
(iv)
incoming data bits (11101) and corresponding gate windows, for various phase angles θ

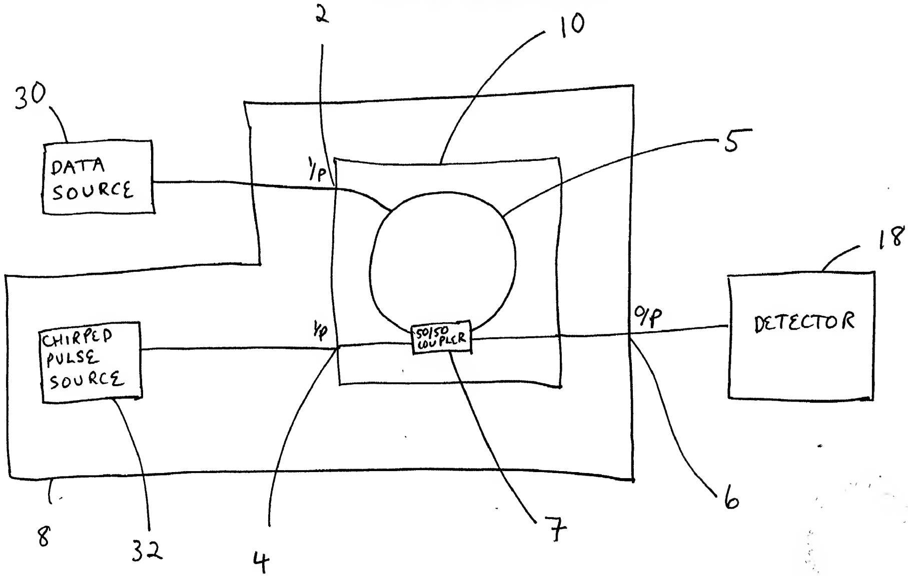

30
DATA SOURCE
CHIRPED PULSE SOURCE
8
32
2
I/P
I/P
4
10
5
50/50 COUPLER
7
O/P
6
18
DETECTOR

Figure 10

A25755 USw

Nixon & Vanderhye P.C. (10/99)
(Domestic Non-Assigned/Foreign)

RULE 63 (37 C.F.R. 1.63)
DECLARATION AND POWER OF ATTORNEY
FOR PATENT APPLICATION
IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

As a below named inventor, I hereby declare that my residence, post office address and citizenship are as stated below next to my name, and I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

COMMUNICATIONS NETWORK

the specification of which (**check** applicable **box(s)**):

☐ is attached hereto
☐ was filed on ______ as U.S. Application Serial No. ______ (Atty Dkt. No. ______)
☒ was filed as PCT International application No. PCT/GB 00/01155 on 27 March 2000
and (if applicable to U.S. or PCT application) was amended on ______

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above. I acknowledge the duty to disclose information which is material to the patentability of this application in accordance with 37 C.F.R. 1.56. I hereby claim foreign priority benefits under 35 U.S.C. 119/365 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed or, if no priority is claimed, before the filing date of this application:

Priority Foreign Application(s):

Application Number	**Country**	**Day/Month/Year Filed**
9907496.5	GREAT BRITAIN	31 March 1999

I hereby claim the benefit under 35 U.S.C. §119(e) of any United States provisional application(s) listed below.

Application Number	**Date/Month/Year Filed**

I hereby claim the benefit under 35 U.S.C. 120/365 of all prior United States and PCT international applications listed above or below and, insofar as the subject matter of each of the claims of this application is not disclosed in such prior applications in the manner provided by the first paragraph of 35 U.S.C. 112, I acknowledge the duty to disclose material information as defined in 37 C.F.R. 1.56 which occurred between the filing date of the prior applications and the national or PCT international filing date of this application:

Prior U.S./PCT Application(s): Application Serial No.	**Day/Month/Year Filed**	**Status: patented pending, abandoned**
PCT/GB00/01155	27 March 2000	PENDING

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon. And on behalf of the owner(s) hereof, I hereby appoint **NIXON & VANDERHYE P.C., 1100 North Glebe Rd., 8th Floor, Arlington, VA 22201-4714, telephone number (703) 816-4000 (to whom all communications are to be directed)**, and the following ~~attorneys thereof (of the same address)~~ individually and collectively owner's/owners' attorneys to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith and with the resulting patent: Arthur R. Crawford, 25327; ~~Larry S. Nixon, 25640~~; Robert A. Vanderhye, 27076; James T. Hosmer, 30184; ~~Robert W. Faris, 31352~~; Richard G. Besha, 22770; Mark E. Nusbaum, 32348; Michael J. Keenan, 32106; Bryan H. Davidson, 30251; Stanley C. Spooner, 27393; Leonard C. Mitchard, 29009; Duane M. Byers, 33363; Jeffry H. Nelson, 30481; John R. Lastova, 33149; H. Warren Burnam, Jr. ~~29366~~; Thomas E. Byrne, ~~32205~~; Mary J. Wilson, 32955; J. Scott Davidson, 33489; Alan M. Kagen, 36178; Robert A. Molan, 29834; B. J. Sadoff, ~~36663~~; James D. Berquist, ~~34776~~; Updeep S. Gill, 37334; Michael J. Shea, 34725; Donald L. Jackson, 41090; Michelle N. Lester, 32331; Frank P. Presta, 19828; Joseph S. Presta, 35329 I also authorize Nixon & Vanderhye to delete any attorney names/numbers no longer with the firm and to act and rely solely on instructions directly communicated from the person, assignee, attorney, firm, or other organization sending instructions to Nixon & Vanderhye on behalf of the owner(s).

1. Inventor's Signature: Alistair Poustie Date: 29/3/00
   Inventor: ALISTAIR (first) J (MI) POUSTIE (last) GB (citizenship)
   Residence: (city) IPSWICH GBX (state/country) GREAT BRITAIN
   Post Office Address: 60 LATTICE AVENUE, IPSWICH, SUFFOLK
   (Zip Code) IP4 5LLN

2. Inventor's Signature: ______ Date: ______
   Inventor: (first) MI (last) (citizenship)
   Residence: (city) ______ (state/country) ______
   Post Office Address: ______
   (Zip Code) ______

FOR ADDITIONAL INVENTORS, check box ☐ and attach sheet with same information and signature and date for each.